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Sustainabilityof aPneumatic Refuse System in the Metropolitan Area: a case study in southern Apulia Region

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Abstract

Urban waste management is a widespread Italian problem, particularly relevant in the south. The large quantity of unsorted waste creates direct discomfort from the collection to disposal and indirect environmental sustainability problems reducing the quality of both rural and urban areas. Since 2011, the production of municipal solid waste, has started to decrease due to the distribution of door-to-door collection systems, but also becausethe reduced share of consumption caused bythe economic crisis (ISPRA, 2014). Nevertheless, the separate collection rates remain too low and the landfill disposal too high related to European averages, resulting unsustainable both from an environmental and socio-cultural point of view. Starting from these assumptions, this research intends to propose a case study methodology for the waste management by using the Pneumatic Refuse System(PRS) as a viable alternative to the traditional collection system.In detail, the research is divided into two strictly consequential phases: the first step analyzes the correlation between the PRS cost and urban density indicator of five municipalities with different number of inhabitant located in the Province of Lecce, from which a general cost trend and consequently, the economic trade-off point have been determined. Starting from this point, the following phase analyses the cost effectiveness of the hypothetical installation of the PRS in one of the previous municipality analysed, in a high-density district. As a result, a general strategy for waste management on metropolitan scale will be identified in order to increase the recycling percentage in the South Italy, justified by the sustainability and by Circular Economy principle (MacArthur, 2013).

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*Keywords:*Waste Management; Pneumatic Refuse System; Density; Metropolitan Area

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1. Introduction

Sustainable waste management is one of the most important issues in urban and rural areas. The total amount of municipal, industrial and dangerous waste produced worldwide annually is more than 4 billion tons (ISWA, 2013). Most of these produced refusesare municipal solid waste and, taking in account the projections, the organicfractiongeneration will increase his quantity by around 45%(ISWA, 2013).Nevertheless, this growth trend needs to be converted into opportunities and managed in a smart way to create resources. For example, PRS is an existing possibility to improve waste management. The PRS is a technological system for waste separated collection composed byan automated vacuum system that allows transportingwaste at high speed through underground tubes to a collection plant where it is compacted and sealed in containers. The system facilitatesa properseparation, increasesrecycling and foster the urban quality (Glave & Russell, 2010).This systemrepresents a high-tech strategy to optimize the smart waste management and it could be integrated in public space, in new district project, in new or existing building.It is highly innovative in some contexts, such as Italy, but consolidated in other European contexts where it is used since many years.The first vacuum system was created in Sweden,at Sollefteå Hospital,in the 1960, designed by the Swedish corporationEnvac; today is diffused in several consolidate urban areas as in Spain, Denmark, Germany, etc.

One major problem of this system is related to the invasiveness of the installation and to the cost of the entire system. Despite this,"the management of waste through underground developed infrastructure can be looked as an important evolution which would allow for the efficient and cost-effective tackling of one of the more pressing needs of modern society" (ISWA, 2013).Effectively, the vacuum system has several strengthsas: collection of recyclable waste near origin place;automatic transport of waste byreducing environmental impact related to energy consumption and gaseous emissions;incentive for recycling;improvement of urban space quality and liveability; high hygienic standards linked to the elimination of bacterial diffusionsand odor problems and limited maintenance requirements (Miller, 2014) (Jackson, 2004). For example, in (Teerioja & al., 2012) PRSis considered superior to traditional collection methods, becauseit reduces the negative impacts of vehicle-based waste collection and makes separation moreattractive for households. In addition, also from the economic point of view, the PRSinstalled in a new residential area lowers costs for households compared to a traditional door-to-door waste collection system(Jackson, 2004). Other studies have examined the positive effects of a PRS in existing built areas. In these cases, the system is convenient in densely populated urban areas,in the buildings under renovation or partial reconstruction (Punkkinen & al., 2012).

The possibility to study the system is an interesting opportunity in a metropolitan dimension in order to manage the entire cycle and the possible waste reuse. The metropolitan dimension, rooted in European countries, and implemented by the recent Italian legislative changes (D.Lgs n.56/2014), represents an chance to rethink the planning methodologies of waste management in the territories and to consolidate new sustainable paradigms summoned. The research is restricted to southern complex geography that represents one of the "most interesting forms the unfinished Italian metropolitan process" (Guida, 2015), characterized by a polycentric system of agglomerations with different dimension but with similar morphotypological and historical features.This research aims to investigate the feasibility of a PRS in this peculiar urban structure of South Italy analysing the economic convenience of the System in an existing urban area. The research is divided into two consequential phases: the first step analyses the correlation between the PRS cost and urban density indicator of five municipalities with different number of inhabitant of the Lecce Province.The second phase analyses the cost effectiveness of the PRS hypothetical installation in one of the examined municipality, in a high-density district. This case study methodologyallows to determine the effective convenience of a PRS and to define the strategies of reusing the organic part of the waste for the energy production processes in metropolitan scale.

2. The normative context

The use of the PRS for the organic waste management on metropolitan scale represents an opportunity, but his should also be analyzed at the regulatory level.The European Legislation Directive 2008/98/EC, in order to reduce waste generation, proposes a legal framework regulatingthe entire waste cycle, with an emphasis on prevention, recycling and recovery, reducing the use of raw materials, by improving the efficiency and the environment and human healthprotection. Member States are required to take steps to ensure that, by 2020, at least 50% of household waste have to berecycled or reused for new products (EC, 2010). In Europe, many virtuous states have already reached important goals: conferring nearly zero waste to landfill with recovery of materials and energy. In Switzerland and Denmark, for example, about 50% of waste goes to incinerator, the remainingis recycled. The Italian situation is far away from European virtuosity: over 50% of Italianwaste ends up in landfills. In Italy, the in force legislation for waste management is the "*TestoUnicoAmbientale*", Legislative Decree 3 April 2006 n. 152. From the decree, it is possible to identify the competence in the field of waste management, useful to recognize possible future strategies in the metropolitan area. In detail, the State is responsible for the definition of guidelines, the general criteria and methodologies for integrated waste management; regions will have to prepare the adoption and the updating of regional plans for waste management and have to approve new plant projects, the licensing of disposal operations and waste recovery and the Territorial Optimum Areas delimitation. Provinces' main role is to plan and organize waste recovery and disposal, perform controls on the management and identify areas suitable to disposal facilities in accordance with local government.

It is, therefore,atthe provincial scale, similar to metropolitan one, on which we could act for organic waste disposal program from different hypothetical pneumatic systems installed in the municipalities, by managing the whole waste cycle with the principle of the Circular Economy (MacArthur, 2013).The Regional Plan of Urban Waste Management (PRGRU - approved by the Regional Council Resolution n.ro 204/2013) of Apulia Region offers the possibility to examine the PRS as effective alternative. In detail, the PRGRU proposes testing of new management models, as PRS, based on self-sustainable use of waste as a resource.

3. Case Study Methodology

The proposed research presents a case study methodology based on the southern Apulia Region contexts and aims to produce a suitable analysis that could be able to generate as first result a series of indicator pointed towards the economic feasibility of a PRS. On the other hand, in order to evaluate the effective cost (per inhabitant) of the system as a whole, it has been defined, as a simple hypothesis, a complete pneumatic refuse system.

The first step of the research analyses the correlation between the PRS cost and urban density indicator of five municipalities, Lecce, Galatina, Galatone, Melissano e Melpignano, chosen with different but exhaustive bands of inhabitants number, representative of the different typologies of the polycentric system of the Province of Lecce. For each selected municipality, we have identified the Urban Morphological Zones (see Fig. 2), based on the historical, functional and morphotypological criteria as: Historical Center, Consolidated City, Contemporary City, Periurban City and Rural Area and Coastal Zone.Processing the available open data (www.sit.puglia.it) related to the territories where the system should be installed, it is possible to obtain a large number of significant parameters such are the total surface of each examined territory, the number of inhabitants living in that places and the total volume of the existing building. The manipulation of these values allows to calculate the urban density ([inh/m^2]) and the building density ([m^3/m^2]). When thegeneric site has been chosen, it is needed to define the delimitation of those areas. The factors that is necessary to determine how extended will those areas be, are number of inhabitants and the covered surface. Regarding the installation of a pneumatic gathering system, the most restricting condition is the surface of the selected area due to the extension limit of the pneumatic system (and then the maximum length of a generic pipe); in fact, this value is limited by the fan performance and the pipe system friction coefficient. When this value has been determined for each area, an hypothetical path of the pipe system (and then his length) and a proper number of waste inserting docks will be calculated. According to the number of floors and to the shape of the generic building, three different categories of docking systems are considered: docks placed on the public area, docks placed in the entrance of every single building or docks placed in every single floor of every single building. The computation of waste inserting docks number follows a different procedure for each case listed before: when each of them is placed on the public area it is necessary to consider a single dock for every 80 inhabitants, while in the case of in-building installation, it is necessary to consider a single dock per building (in the case of in-entrance installation), or a single dock per floor (in the case of each floor installation). After *in-situ* inspections and thanks to satellite instruments (i.e. Google Maps and Google Earth) it is possible to identify the number of floors (considering the floor height equal to 3 metersand assuming a mean value of the generic building total height)and then to calculate the building density; from this last value it is possible to compute the urban density.The number of multi-floor buildings and the number of floors as well are obtained by fixing the number of floors per building and the number of apartment per floor.Supposing that a single family unit is composed by 4 people, the number of docks per building and the number of docks per floor can be simply calculate just knowing the number of inhabitants.Starting from the computation of these values, it is possible to summarize the information related to the examined municipalities and to each their Urban Morphological Zones and to determine the PRS specific cost (per inhabitant).

Table 1 – Examined Cities: Characteristic data

Municipality	Urban MorphologicalZone	Inhabitants	Docks Nr.	Length [m]	Density [inh/m^2]	Total Cost [€]	Specific Cost [€/inh]
Lecce	Historical Center	1954	25	5050	0,0054	€ 2.965.666	€ 1.517
	Consolidated City	3435	43	5000	0,0103	€ 3.514.581	€ 1.023
	Contemporary City	3382	43	5100	0,0088	€ 3.557.571	€ 1.051
	Periurban City	2298	29	4600	0,0064	€ 2.899.574	€ 1.261
	Rural Area	37	1	1400	0,0001	€ 632.338	€ 17.090
	Coastal Zone	188	3	1500	0,0005	€ 736.280	€ 3.916
Galatina	Historical Center	1279	16	3800	0,0062	€ 2.143.083	€ 1.758
	Consolidated City	2466	31	4700	0,0090	€ 3.003.517	€ 1.217
	Periurban City	860	11	2300	0,0067	€ 1.501.579	€ 1.746
	Rural Area	53	1	800	0,0002	€ 374.397	€ 7.064
Galatone	Historical Centre	586	8	1400	0,0077	€ 856.591	€ 1.461
	Consolidated City	1983	25	4000	0,0096	€ 2.514.269	€ 1.267
	Periurban City	724	10	2000	0,0044	€ 1.501.579	€ 2.074
	Rural Area	107	2	1200	0,0003	€ 576.834	€ 5.390
Melissano	Historical Center	719	9	2500	0,0048	€ 1.359.959	€ 1.891
	Consolidated City	1313	17	2700	0,0058	€ 1.700.668	€ 1.295
	Periurban City	766	10	1800	0,0048	€ 1.501.579	€ 1.960
Melpignano	Urban Center	765	10	1900	0,0032	€ 1.132.494	€ 1.480

Referring to Table 1, last two columns report either the total and the specific cost of the PRS; the specific cost is computed dividing the total cost by the number of inhabitants.The total cost of the PRS system is calculated by considering the unitary cost of every installed facilities and multiplying it for the proper quantity. For the same reason, pipe system cost per unity of length have to be multiplied for the relative length, the cost of the single inserting dock have to be multiplied for the number of docks and so on. The specific costs of every element of the system are taken from commercial catalogues or by studies findable in literature. It is now possible to plot the cost values and to obtain a power regression curve that can show the trend of the specific cost as a function of the urban density. That kind of relation is very important; supposing a fixed pay-back period per family unit and a monthly payment threshold for each of them, it is possible to attain an economic trade-off point that can define the suitability of whether install a pneumatic system or not. It is possible, though, to define a time related cost evolution that can bring out different cost per family unit depending on the fixed time interval. This allows to consider different repayment plans and different repayment periods according to the tax regime, the public subsidy (if provided) or the population wealth. Considering the results of the specific case regarding the five examined municipalities, it is immediate to notice that the trend of the specific costs is the same independently of the municipality. It has been verified that the specific cost trend has a decreasing trend with the increasing of the urban density value.

Once the analysis run before has terminated, it is possible to make the second phase of the study start; as previously stated, the last phase of the proposed analysis regards the cost effectiveness of the installation of the PRS in one of the municipality analysed (more specifically, Lecce) compared to the costs relative to the actual way to manage waste. In order to make this comparison reasonable, the different cost entries have to be considered singularly and for each one it is necessary to perform a variation cost forecast relatively to the actual traditional waste collection system. According to the graph in Fig. 1**,** the cost analysis has been run corresponding to a urban density equal to about 0.0065 inh/m^2, that is the value that describes the characteristics of the Periurban City area.

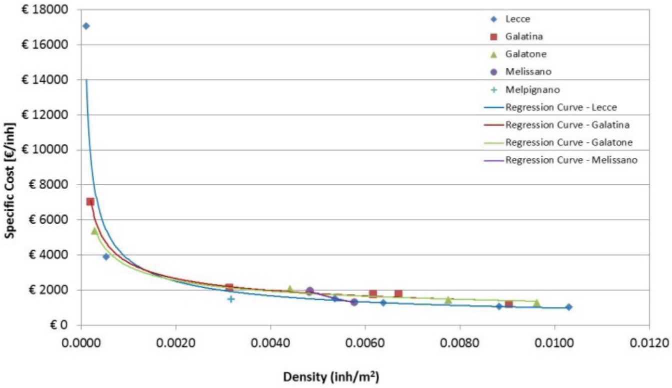

Fig. 1 Regression curve of specific cost as a function of the population density

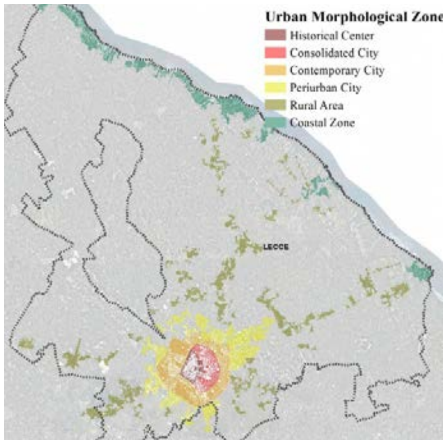

Fig. 2 Urban Morphological Zones relative to the city of Lecce

4. Main findings and strategy of metropolitan waste management

Regarding the results related to the previous analysis and considering the output values related to the case of Lecce (the most complete one), the use of a waste transport and management system like the one presented in this purpose can enable a substantial public money saving and at the same time, a remarkable CO_2 saving process. Both these effects are enabled mainly for two strictly consequential reasons. The first one is that using a buried pipe system to convoy the waste in specific places will remove from urban streets most of the vehicle deputy to the collection and this brings either a reduction of costs (because the savings of investment related to the different type of vehicle) and a reduction of their polluting emissions (and then both CO_2 and PM10).

An estimation of the cost saving, has been made for the city of Lecce; considering all the data achievable from the Lecce Municipal Approval n.82/2013, it is possible to estimate the amount of money that could be saved. More specifically, the cost presented in the following table are referred to the percentage of Lecce's inhabitants that could take advantage of the PRS that, according to the threshold urban density (0.0065 inh/m^2), is about 70% of the total population (ISTAT 2001 – DPP Lecce Relation).

Table 2 – City of Lecce – Actual and Hypothetical Waste Service Costs comparison

Cost Items	Actual Collecting System	PRS System
Waste Service Management Costs	€ 7.660.771	€ 4.870.112
Waste-relatedActivitiesCosts	€ 7.034.608	€ 4.210.008
Eco-Tax	€ 1.021.161	€ 204.469
Total Costs	€ 16.674.817	€ 10.102.485

The different entries costs reduction has each one different explanations; the one relative to the waste service is caused by the severe reduction in the number of truck and vehicles deputy to the waste collection. Given this reduction even the number of worker can be reduced causing the difference between the actual cost and the PRS one. Finally, using an highly efficient system likePRS allows to reach very high recycling percentage. That enables the reduction of the taxes that the city of Lecce have to pay because the high quantity of not recycled waste. As a result of this estimate, assuming that the waste separate collection percentage will be equal (or superior) to 65% (starting from an actual value that is less than 20%), the cost saves are computable in almost the 40% of the overall (actual) spending.

The second aspect, the one directly related to the environmental issue, is remarkably more interesting because it allows to save either CO_2 and money and then to boost health and richness of the inhabitants. The pneumatic waste collection and management system (like the proposed PRS) in a metropolitan area, allows to enable a very interesting aspect that a system installed in smaller area could not enable. It is possible, in fact, to start the so-called "circular economy" phenomenon (MacArthur, 2013), because the possibility to close the loop of the whole process by using the organic fraction of the total waste as a component of the bio-methane generation process: the anaerobic digestion. By means of this conversion process, the organic part of the waste will be mixed with other biomasses and let them macerate in absence of oxygen with the purpose of producing bio-gas. Once that gas is produced it can be used in a bio-methane power plantto produce electric energy or to fuel in general piston combustion engines. The residual solid matter deriving from that process will be not a further waste because it will be used as fertilizer. In this way the electric energy necessary to make the system works could be supplemented by the energy deriving from the digestion process. It is obvious that both this aspects enter the “loop” earlier mentioned because they give the possibility to close the treatment process of the organic part by generating energy in a circular and eco-friendly way. The possibility to use the bio-methane as fuel for trucks is another aspect that allows to reduce CO_2 emissions and particulate, enabling the chance to finally obtain a less pollutant wheel transport.

This kind of “virtuous loop” could be enabled only in metropolitan areas due to the relative high quantity of organic fraction requiredand due to the variety of biomasses which are needed for the production of biogas. In a smaller scale, effectively, the produced quantity and variety could not be able to sustain the cycle, making all the process described before less advantageous or even disadvantageous.

5. Conclusion

The waste management at metropolitan scale can be justified by the principles of circular economy starting from the analyzed case study methodology, based on the feasibility of the PRS in high urban density contexts, with the application of the competences on the organization of waste recovery and disposal that Provinces have in Italy.In detail, it is proposed the economic pressure sustenance of the technological system thanks to the use of organic waste material collected by the Pneumatic Refuse System for the production of electrical energy and for vehiclesfueling, which is useful both to feed the entire infrastructure and to provide cost savings and better environmental conditions to citizens. The use of a waste transport and management system of multiple PRS of different municipalities (metropolitan scale like the one presented in this purpose), can enable a substantial public money saving and at the same time a remarkable CO_2 saving process. In fact, using a buried pipe system to convoy the waste in specific places can remove most of the vehicle deputy to the collection and this brings either a reduction of costs and a reduction of pollutant emission, as well as part of the convoyed waste, and more specifically the organic fraction, can be used as an energy generator via an anaerobic digestor making the whole PRS process more sustainable than any actual traditional collection system. This system integrates technology, environment, territory and society and provides a significant boost to the urban space and life quality of the community, if it is applied in a system of municipalities with high urban density on the base of the performed analysis.

Future researches, will focus on the definition of the metropolitan strategies of integration aiming to the process standardization and definition of specific criteria.

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